32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19-22, 2019

To what extent do electric car drivers utilize the flexibility options in two-car households?

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Summary

In two-car households, potentially a BEV can drive longer, circumvent range limitations, while having a smaller battery [1]. Do real households utilize these options? In 20 two-car households, both vehicles were GPS-tracked before and after replacing one of the conventional cars of their own choice with a short-range BEV.

The households mostly replaced their smallest car. For below-range distances, the households on average utilized the potential to around 69% and 56% in single and overlap trips, respectively. The heredity from the pre-trial period driving was small.

Keywords: BEV, case study, user behaviour, range, modelling

1 Introduction

In a changing world an important question is how new technological and organizational options are possibly and actually utilized. Electrified vehicles are one of the available options to achieve less use of fossil fuel and reduced emissions of greenhouse gases and other pollutants from transport, especially in countries or regions with clean electricity production systems [2]. Due to its comparably lower operational but higher fixed costs, the relative economic viability of battery electric vehicles (BEVs) is more advantageous with high annual driving, but this, in turn, tends to aggravate the range and charging limitations.

Could two-car (or generally multi-car) households by circumventing these limitations be potential private BEV buyers beyond current innovators or early adopters? We have earlier shown, that, in Sweden, the flexibility available in two-car households represents on average a value of around $7 000 for the BEV owners in these households, or in other words, this is the amount a two-car household could (rationally) pay more for a BEV compared to a one-car household [1]. Compared to a one-car household, the two-car households can drive longer on electricity, which is cheaper than driving on gasoline or diesel, and avoid costs for possible unfulfilled car mobility due to the BEV range limitations, while still having a small and thus cheaper battery. The total value is roughly equally divided between these three factors [1]. This estimate of the theoretical potential based on car movement patterns utilized GPS-logging of both cars simultaneously for around two months in 64 commuting two-car household in the Gothenburg region in Sweden.

But *to what extent do electric car drivers utilize these options made possible in two-car households?* Even if there from a pure cost minimization perspective are reasons to optimize the use of the vehicles for maximized BEV driving, there could in real situations be several reasons why the principal potential derived from car movement patterns alone are not fully used. For instance, some driving may require specific equipment which possibly happens to be available only in the non-BEV, such as a tow bar or a child seat. The non-BEV can be preferred in some of the driving for safety, reliability or capacity reasons. Psychological factor such as “my car and your car” and plain habits evolved in the time when only the conventional vehicles (CVs) were available may inhibit the use of the cars for maximum BEV driving. Or simply, households may not be motivated enough to put efforts into maximizing their BEV use, which will involve maybe daily considerations and decisions on who will use which car when and for what.

To our knowledge, there are no published studies devoted to the question stated above by actually measuring and evaluating actual BEV driving in comparison to what principally could be achieved. Besides [1], only one study has analysed BEV options based on logged movement data for both cars in two-car households with two conventional (fuel) cars [3]. It concluded similar to [1], using data from the Seattle region, that a BEV with a modest range (160 km) appears to be viable at costs that are likely to be achieved in the near future. Others have used logged data from two-car households but specifically only estimated the potential for a BEV when it substitutes one of the cars’ driving [4,5]. In [4], using the same Seattle data set as in [3], it was found for a BEV (160 km range) replacing the least-driven car only in multi-car households that the range limit is reached less often than in single car households. In [5], based on GPS data logging of one car in different single- and multi-car households with conventional cars, it was shown that the number of days requiring adaptation (DRA) when replacing a BEV with a specific range for a conventional car was generally lower when replacing the “second car “, i.e., the one with shortest annual driving, in two-car households than the car in single car households. The study also concluded that the economics was on average somewhat more favourable when replacing the second car.

2 Method and data

2.1 The BEV trial period and Data

In 25 of the above-mentioned 64 households [1], we have in a subsequent BEV trial project tracked for around three to four months both vehicles after replacing one of the conventional cars with a BEV, a Volkswagen e-Golf my 2015. In these unique projects, we thus have car movement loggings from both before and after the replacement of one of the cars with a BEV. However, in only 20 of the households, the logging was successful enough to give rise to a tracking of the vehicles simultaneously for a longer period with high quality, why we here for the BEV options and use analyses only utilize data from these 20 households.

For the BEV trial project, households were selected from the 64 households by using a combination of earlier data as well interviews. The intention was to get a broad distribution in various factors such as the households’ size and car properties, commuting distances and charging options at work. Requirements were the feasibility to easily install a home charging equipment and, to make comparisons possible, that the overall driving pattern prerequisites had not changed significantly since the previous measurement, such as changes in commuter distances due changes in work or home locations. Of the households finally offered a BEV trail period almost all accepted.

An intention for the trial period was to mimic as close as possible a situation in which the households had a BEV of their own. No specific use of the BEV was suggested and they had to plan and facilitate their mobility themselves.

A home charging equipment was installed in a suitable place. All households were able to finally charge by 230V 16A, corresponding to roughly a power of 3 kW at the battery. (Some households also had the option to charge at the workplace.)

One of the cars, of the households’ own choice, were substituted for the BEV. The replaced car was parked, by the households or us, and was promised not to be used. (For convenience, exception was made for any necessary service or compulsory vehicle inspection, though.). The replaced car was checked for any use during trail period.

The economics should preferably reflect the short-term operational economics when owning a BEV. Thus, the households paid for the electricity charged at home, parking costs, and congestion taxes (which are there in Gothenburg), as well as any traffic and car insurance deductibles (yes, it actually happened!).

The trial period should be long enough to well transcend any initial BEV excitement and unfamiliarity as well include different driving situations. The trials were distributed on three separate periods: March – Sept 2015 (10 households (hhs)), Oct 2015 – Jan 2016 (10 hhs), and March – June 2016 (5 hhs), and thus covered different seasons of the year including vacation and holidays periods, and winter conditions with colder climate and driving with studded tyres. Due to fussing measurement equipment only five of the ten households in the first period are included in the movement pattern analysis here and then from April/May and further on. No efforts were made to fit the trial period of the single household to that household's previous pre-trial period, though.

During the trial period GPS-logging (1Hz) was performed of position and speed of both cars simultaneously. For the BEV also the odometer readings, speed, State of Charge (SoC), and outdoor temperature were extracted from the OBD system. Point of times and energy (kWh) for each charging session were registered from the home charging equipment. Semi-structured interviews with the household members were performed before and in the end of the trail period. Here we use only trip level data in the form of trip distances, point of times for trip starts and stops, though, although much of the other data has been used for control and filtering, for instance, GPS distances have been checked for consistency with the odometer readings.

2.2 Assumptions and Modelling

The analysis and comparison of the actual and possible utilization of the BEV is done as an ex post analysis of the registered trip data from the trial period. We use previously developed optimization programs to estimate the maximum possible BEV driving considering the car movement patterns as well as range and charging limitations [1]. In the optimization we assume reasonably that the cars are possibly exchanged only when they are simultaneously at home. We therefore focus home-to-home trips, i.e, trips are added up to the aggregated distance for all trips from leaving home to coming back, and the corresponding with start and stop times. Only home-charging is assumed. The optimization programs can consider different charging rates, but here we assume a much higher charging rate than the actual to avoid a mixture of restrictions on possible driving. We have earlier shown that charging rate limitations are of minor importance compared to range limitations [1].

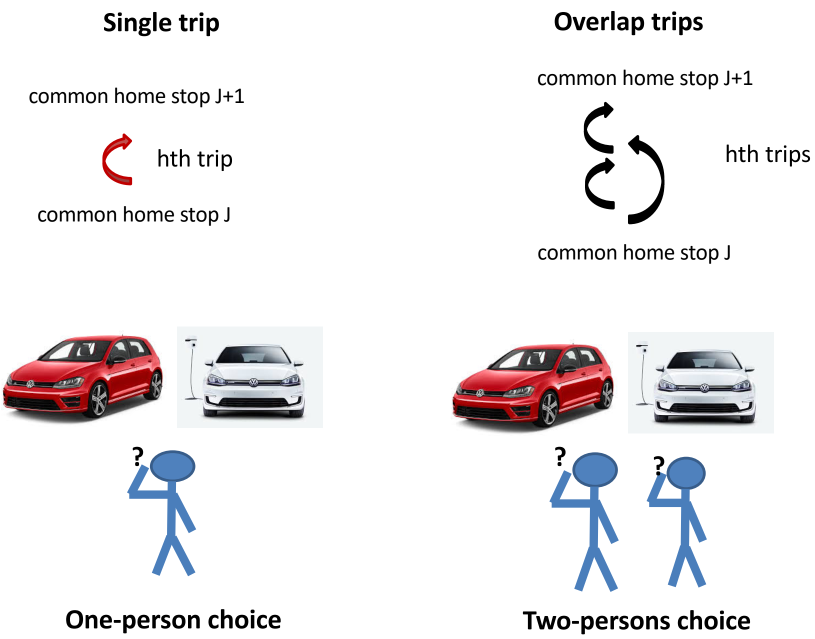


Figure 1: The two different choice situations dependent single and simultaneous driving in two-car households.

A constant BEV range of 120 km is assumed. The used e-Golfs have a 24 kWh battery and the average logged energy use during the trial is 18.3 kWh per 100 km. This gives with 90% utilization of the SoC an average range of 118 km. The specific energy use varied considerably between trips and was generally higher during cold periods and when studded tyres were mounted.

There are then two principal decisions to be taken in these two-cars households: the “single person” and “two-persons” choices, Fig 1. In the first situation there is only a need for one car between common pauses for the cars at home, so the question for the driver is which car to choose, the BEV or the CV. In the two-person situation, there are two drivers that simultaneously want to drive in time overlapping trips and therefore have to distribute the two cars between them.

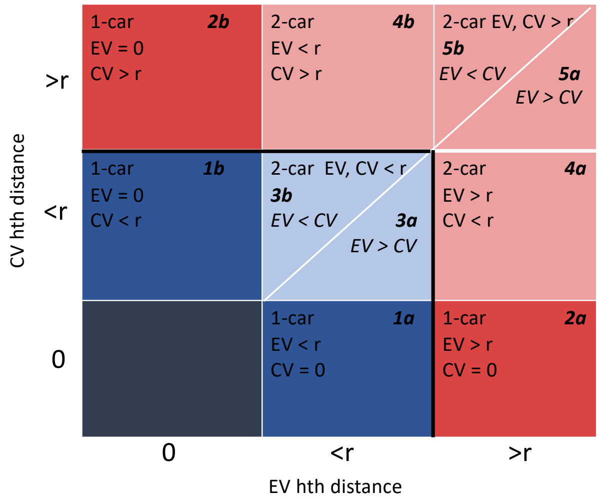


Figure 2: Different combinations of home-to-home distances between common stops at home in two-car households with one BEV (EV in figure) with range r and one CV.

The choices also need to consider the range and home-charging-only limitations for the BEV. We therefore end up in the different possible combinations of logged home-to-home (hth) trips depicted in Figure 2. Dark blue and red are single trips where blue ones are below range and red above. Light blue and red are overlap trips. Light blue corresponds to both car’s driving between common stops consists of hth trips below the BEV range r. Principally a choice who should use which car can then be done. For the driving in the light red boxes 4a and 4b at least one car’s hth trip(s) is longer than the BEV range and in the modelling the BEV has to take the other car’s driving. Occasionally both cars have driven longer than range outside home simultaneously. Probably the actual BEV then has charged outside home, which is actually the case also for the actual driving in box 4a. In the further analysis we group the driving in four groups (the different colours in Fig 2): single trips below range (boxes 1a,b), single trips above range (boxes 2a,b), overlap trips below range (box 3a,b), and finally overlap trips above range (boxes 4a,b with one car with a trip above range, and box 5 with both cars’ trips above range).

3 Results

3.1 The replaced car

As mentioned, which car to replace with a BEV was up to the households to determine. Which car can influence the partitioning of the households’ driving between their cars; for instance, car properties can make one car more convenient for certain trips or a certain driving pattern is inherited. In Table 1 the coincidences of the actual choices with different car, driving pattern and infrastructure properties are given. Only household with a clear difference in the properties are included, i.e., for instance, households with cars of roughly the same size are excluded. Of course, the households are few and there are large correlations between many of the properties. The result should therefore be interpreted with care.

Generally, it seems that the car properties are the most important ones; most households have chosen to keep the “best” car. The highest score is for keeping the largest car; about nine out of ten households kept the largest car. Also, some driving pattern properties were favoured: DRA and Longest annual VKT (vehicle kilometres travelled). DRA (days requiring adaptation) is the number of yearly days that the driving exceeds the BEV range and thus can't be met by a BEV by only home charging during the night. The Gini coefficient is a measure of the confinement of the driving; higher Gini coefficient corresponds to most distances in a narrower range and tends to favours the BEVs economics. Only 20% of the households had (stated known and exclusive) charging option at work, but the correlation with car replacement was low.

Table 1: The coincidence of different car, driving pattern and infrastructure properties with actual kept/replaced car. Score gives the number of households supporting the coincidence or not, respectively, and within parenthesis the share of households supporting. Rank sorts the households from highest to lowest share. (Only households with a clear difference in properties are included, i.e., for instance, households with cars of roughly the same size are excluded.)

KEPT/REPLACED	SCORE		RANK
Car properties			
KEPT the *Largest car*	19 – 2	(90%)	1
KEPT the *Newest car*	15 – 8	(65%)	6
KEPT the *Diesel/E85 car*	10 – 3	(77%)	2
KEPT the car with a *Towbar*	12 – 4	(75%)	3
Driving pattern properties			
KEPT the car with *Shortest commuter distance*	11 – 10	(53%)	8
KEPT the car with *Longest annual VKT ("1st car")*	12 – 6	(67%)	5
KEPT the car with *Most DRA*	14 – 6	(70%)	4
REPLACED the car with *Lowest Gini-coefficient for hth distances*	16 – 9	(64%)	7
Infrastructure properties			
REPLACED the car with *Charging option at work*	2 – 3	(40%)	9

3.2 Movement pattern limitations

We first look at the limitations due to the car movement patterns. Different household car movement patterns make possible more or less BEV driving due to two basic limitations.

Overlap limitations. Overlap (simultaneous) trips will inevitably disable the BEV taking up some of the driving even though all trips are shorter than the BEV range. The larger the overlap driving share of the total driving the more is the possible BEV driving limited. But also, the smaller the difference in distances between the longest and shortest overlap driving, the smaller the range of possible BEV driving.

Range limitations. Movement patterns with a high share of hth trips above the BEV range will be less suitable although not necessarily impossible. In the trial the actual BEV range was relatively short, as well as the assumed range in the analysis, though. With a larger BEV range this drawback will be less severe. Also charging options outside home, such as destination charging and fast charging, may alleviate the effects. But in many instances, the option in two-car households to choose which car to use for which trips can alleviate the effects.

Figure 3 shows the possible BEV driving due to the overlap and range limitations. The possible BEV driving generally increases with the total household driving, Fig 3a. The overlap driving limits the possible BEV driving to around 80%, with a range of 70 to 90 %, Fig 3b. There is no clear tendency to correlation of this limit with the possible BEV driving share. The range limitation to possible BEV driving varies considerably more between the households, it varies between almost zero and 50%, though. It is therefore the dominating factor determining the possible BEV shares, which vary with a factor of two between a low 38 and a high 76%. The minimum or necessary BEV driving is a mirroring of the overlap limitations, and thus varies between 10 and 30%. (Some of this minimum driving is possibly above range, which occurs when both cars drive hth distances above range simultaneously, i.e, driving corresponding to box 5 in Fig 2).

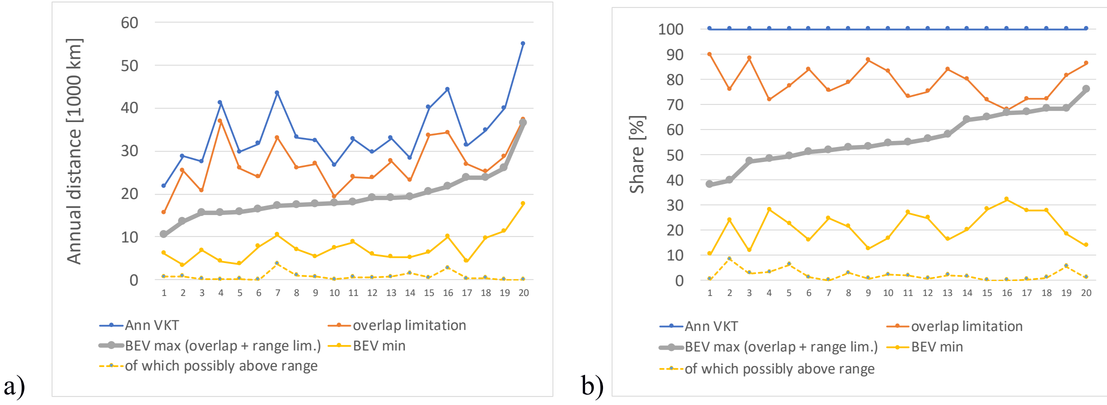


Figure 3. The possible annual BEV driving in the different households ordered after increasing a) possible BEV distance, and b) possible BEV share of total distance driven.

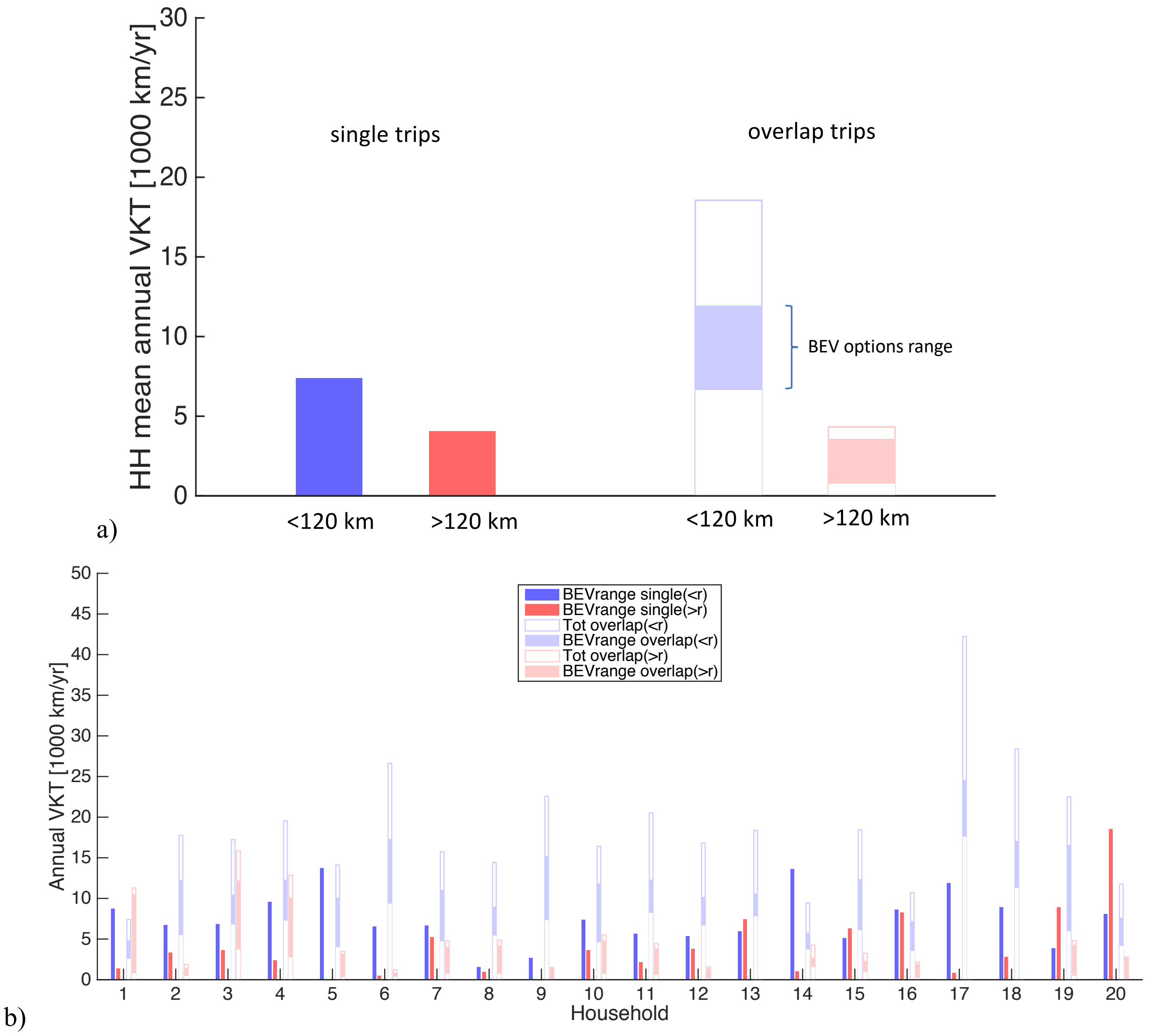


Figure 4. The potential annual BEV driving from the movement patterns, divided into above and below the BEV range of 120 km and single and overlap driving, respectively. In each category, the coloured shares and the crosses make up the possible range of the BEV driving and the actual BEV driving, respectively, for a) household average, and b) individual households.

Figure 4a gives the average household annual distances in the four different trip combinations described in connection to Figure 2. Overlap trips being about 2/3 of the total driving dominate. Below range overlap trips account for around 72% of the driving and the possible BEV driving for overlap trips is larger than for single trips. But the difference between possible and necessary BEV driving is relatively small and accounts for on average 29% of the overlap driving. This means that in many cases the overlap trips are of roughly the same length.

For overlap trips the share of distances above range is much smaller than for single trips. The necessary BEV driving is also short, which means that driving of distances above range simultaneously with both cars does not occur that often, which also was concluded in [1]. Reasonably, it is often so that when a household drives a longer distance away from home with one of the cars, for instance, on weekends or vacations, all or most family members are joining, and the other car is parked at home. Some or most of the necessary BEV driving can be shorter than the range (compare category 4 in Fig 2). It can be seen that on average these possible below-range distances are very small compared to all distances below range (≈ 3%). Single trips above range constitute about 35 % of the total single trip distance.

The movement pattern limitations differ considerably between the households, though, Figure 4b. The share of the driving above the BEV range varies from very low (hhs 7, 9, 17, 18) to almost half (hhs 1, 3) or more than half (hh 20) of the household driving.

For distances below the BEV range, the share of overlap driving dominates single trips except for one household (hh 14). This implies that the possible BEV driving is dominated by overlap driving in 15 (75%) of the households. However, the potential scope in BEV driving due to choice of car (i.e., the difference between min and max) is larger for overlap trips in only 5 (25%) of the households.

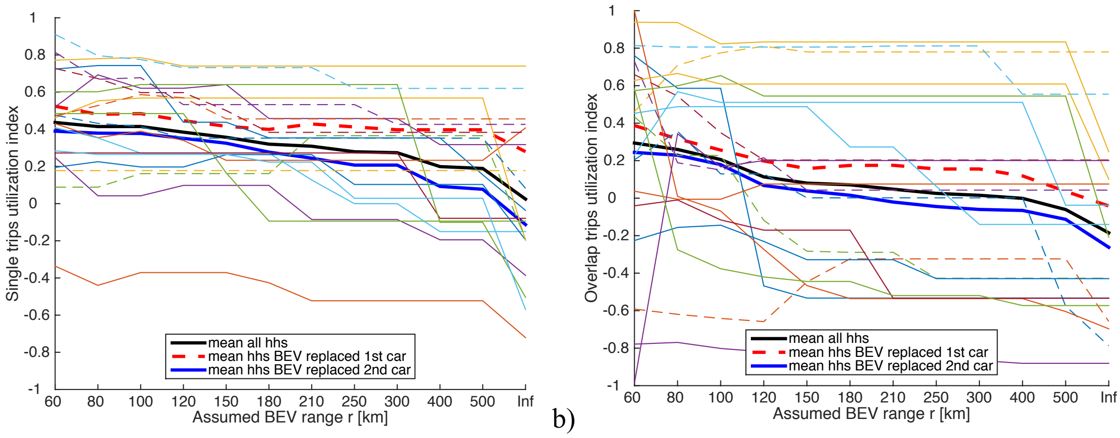
3.3 Utilization of the flexibility options

3.3.1 Utilization index

Figure 5 illustrates the actual utilization of BEV options in single and overlap trips, respectively. It is given in the form of a utilization index, Eq 1, which varies linearly with the actually driven BEV hth distances below assumed range *r* between the end values of -1 and +1 for minimal and maximal possible use, respectively, of the BEV in individual households.

$$\textit{utilization index}\,(\text{BEV range } r) = \frac{\text{BEV}_{\text{actual}}(<r) - \text{BEV}_{\min}(r)}{\text{BEV}_{\max}(r) - \text{BEV}_{\min}(r)} \cdot 2 - 1 \qquad (1)$$

The index is thus equal to zero for equal driving distances for the BEV and the CV on the possible driving option range for the BEV. The index is estimated for various assumed ranges *r* (x-axis).



a) b)

Figure 5. The actual utilization of the BEV in trial period in the different two-car households depicted with a utilization index for different BEV ranges for a) single trips, and b) overlap trips. Dotted lines: indices for households, which replaced the 1st car; solid lines: indices for households, which replaced the 2nd car. For index definition see text.

In the single trip case, Fig 5a, the utilization for distances below an assumed BEV range of 150 km, the BEV is chosen for more of the possible distances than the CV in all but one (95%) of the households. The household average utilization index at 120 km is a full 0.38. The BEV is thus used for on average 69% of the total below-BEV-range single trip household-weighted total distance. For an assumed “infinite” BEV range, the utilization index is still above zero, meaning that the BEV on average has been somewhat preferred over the CV for single trips, when measured as actual distance driven.

In the overlap trips case, Fig 5b, the utilization varies extensively between the households; at 120 km the index takes values roughly between plus and minus 0.8, with an average of 0.11. Of the households, 12 (60%) have an index above zero at 120 km. For longer assumed ranges the average index finally falls below zero at 400 km. The index 0.11 means that around 56% of BEV potential in overlap trips below the assumed BEV range is driven by the BEV.

Both indices adopt, on average, their highest values for distances below 60 km and then monotonically decrease with increasing assumed BEV range, i.e., the shorter the distances the higher the share of BEV driven distances. Overall the BEVs have performed 47% of the aggregated distance driven in the households.

3.3.2 Heredity of driving pattern

Does the utilization depend on the which car was substituted? It could be hypothesized that the driving is inherited and the BEV use does more follow the movement pattern of the car it replaced than utilizes the options to maximize the driving.

In Fig 5 the households are also divided into households that replaced the 1st car and 2nd car, respectively; of which there are seven and thirteen households, respectively. The average utilization is larger for households replacing the 1st car than for those substituting the 2nd car, although the difference is not that large, neither in the single nor in the overlap trips case.

Figure 6 shows the corresponding utilization indices for the replaced cars in the pre-trial period. Here the differences between the 1st and 2nd car in uptake of the household driving are considerably larger, around 0.4 units for single trips, but especially for overlap trips: around 1. While, for single trips, the utilization has on average increased both in case of 1st and 2nd car replacement, for overlap trips, the high utilization of the replaced 1st car in the pre-trial period (on average ≈0.5) has not been transferred to the substituting BEV (≈0.2).

Comparing the replaced car in pre-trial period with the trial period BEV reveals that the utilization index has overall increased on average almost 0.5 units (from around -0.1 to 0.4) for single trips and 0.2 units for overlap trips at BEV ranges up to 120 km. This means that the inferior uptake of distances by the replaced car has been turned into a situation where the BEV performs the majority of the driving.

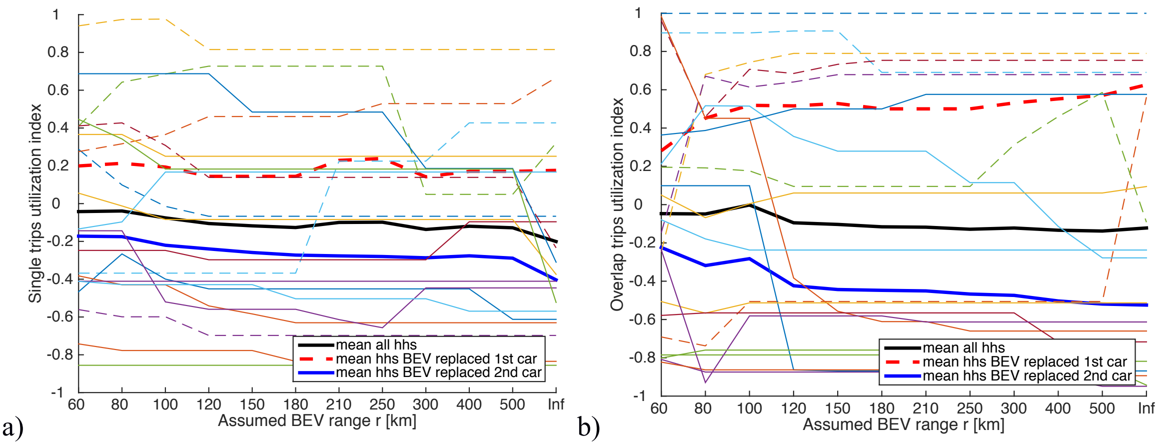


Figure 6. The pre-trial period utilization index of the replaced car in the different two-car households for a) single trips, and b) overlap trips. Dotted lines: indices for households, which replaced the 1st car; solid lines: indices for households, which replaced the 2nd car.

We can also see that the decrease in average indices with assumed BEV range are larger for the BEV than the replaced car, reflecting the effects of the limited range of the BEV; the increased driving for the BEV compared to the replaced car holds for distances below BEV range only. However, overall the BEV uptake of the households total driving is 47%, while the replaced car coves less than that of the pre-trial period's driving, thus still an overall increase in share of driving.

We can conclude that the heritage is quite small; the BEV share of the driving has increased considerably and the big pre-trial difference between 1st and 2nd car has to large extent disappeared.

3.4 BEV occupation frequency and speed, and daily distances

According to Section 3.3, the BEV and CV uses differ. The BEV has on average a larger share of the distances driven below range and for single trips compared to the CV. How does this affect the BEV time of use compared to the CV? There are two interesting perspectives on time of use. First, when is the car driven, i.e., when do its trips take place or when is it thus not parked. Second, when is the car occupied, i.e., when is it away-from-home and not parked at home, and therefore when can it not possibly be used by another household member, and also, if a BEV, cannot be connected to the home charging equipment. The *occupation frequency* gives the daily average number of times the cars are occupied at different times of the day.

Another interesting aspect is the intensity of use or average away-from-home speed or *occupation speed*. The occupation speed multiplied by the occupation frequency gives the time of day distribution of *daily distances* driven when occupied or away-from-home. For a given distance driven, the higher the occupation speed, the more the BEV can be at home either for charging or for possibly being further utilized. We therefore here focus frequency and speed of occupation rather than of use.

Figure 7 shows time of day distributions for average occupation frequency and speed and daily distances for the hth trips below the assumed BEV range of 120 km[1]. We see in Fig 7a, that in weekdays, overlap trips are dominating the occupation frequency. In daytime, on average more than one car is away-from-home simultaneously. In the weekends the cars are more occupied by single trips, though. Single trips are also relatively more frequent in the afternoon/evenings. The total average occupation frequency for weekdays and weekends are 0.62 and 0.22, respectively, meaning that the cars are together away-from-home about 14.9 hours (= 0.622*24) and 5.3 hours in weekdays and weekends, respectively.

The BEV dominates the occupation at any time of the day (Fig 7b). It is away-from-home more than the CV in the weekdays, and relatively even more so in the weekends.

Generally, the intensity of use when occupied is higher for single trips, in weekday evenings, and in weekend daytimes, as illustrated in Fig 7e, which depicts the average occupation speed for the two trip types. We can note that this speed is about twice as large for weekend single trips than for weekday overlap trips. The occupation speed is considerably lower during the nights reflecting the fact that shorter-than-BEV-range overnight trips is combined with being away-from-home for a long time.

Combining the occupation frequency (Fig 7a) with the occupation speed (Fig 7e) gives that the average distances driven when away-from-home, Fig 7c. In the weekdays, overlap trips dominate during daytime, but the distances driven in evenings are as large in connection to single trips. In the weekends, the driven distances are mostly performed by single trips, and especially so in the afternoon/evenings.

The BEV stands for most of the distances driven at (almost) all hours of the day both in weekdays, and (especially) in weekends, Fig 7d. The average daily distance driven is 44.0 and 36.8 km/day in weekdays for the BEV and CV, respectively, and corresponding distances for the weekends are 29.1 and 16.1 km/day. The BEV daily distance is thus 20% longer than for the CV in weekdays, while it is 80% larger in weekends. In total the BEV and CV below-the-BEV-range daily distances are 39.7 and 30.9 km, respectively.

The average occupation speeds in weekdays are roughly the same for the BEV and the CV, but slightly higher (≈10%) for the BEV in the weekends. But due to, in the weekends, the generally higher occupation speed and the larger share of the driving taken up by the BEV, the overall occupation speed for the BEV is overall about 4 % higher than for the CV for hth trips below the assumed BEV range of 120 km.

Fig 7f gives for completion the to Fig 7d corresponding figure for hth distances longer than 120 km. For longer distances than the BEV range, the CV performs most of the driving. Also, overnight trips are a large part of these longer hth trips. The average daily distances are 3.3 km and 20.4 km for the BEV and the CV,

[1] One household with a lot of nighttime commuting is excluded here, due to its specific movement pattern.

respectively. The total BEV and CV daily distances add up to 43.0 and 51.3 km, respectively. The BEV thus covers 46% of the total driving in the nineteen households considered here.

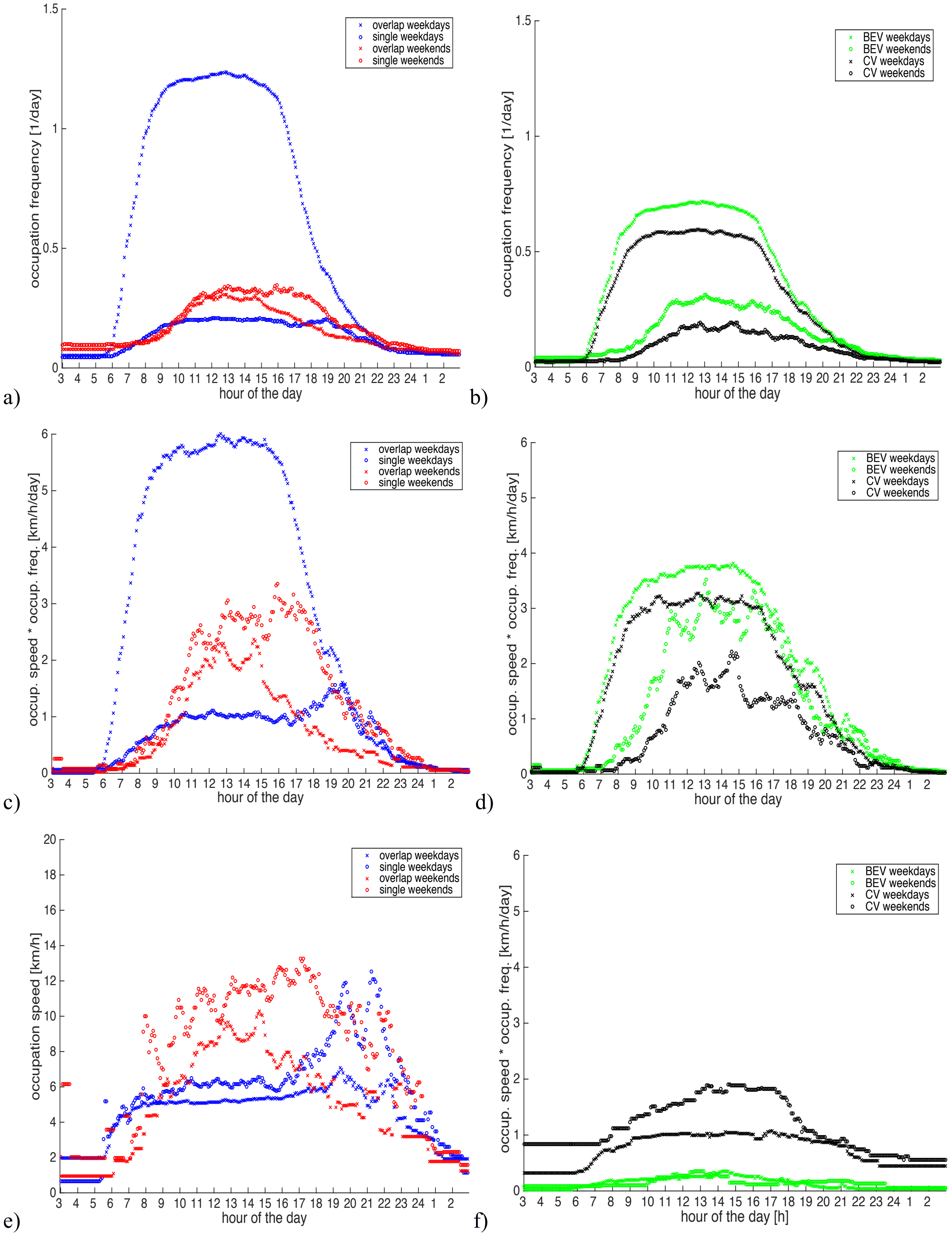


Figure 7: For the hth trips below the assumed BEV range of 120 km, time of day distributions for average occupation frequency for a) single and overlap trips, and b) the BEV and CV, driven daily distances for c) single and overlap trips, and d) the BEV and CV, and for e) average occupation speed for single and overlap trips, and finally f) driven daily distances for the BEV and CV above BEV range.

4 Discussion and Conclusions

The analysis here is based on the behaviour in real households having a BEV at their disposal. But of course, it was a BEV trial rather than the households had a BEV of their own. We have tried to emulate the economics with lower operational costs and having a long enough period to go beyond any initial peculiarities in the adaptations to a BEV. But still they knew it was for a limited period. All around this specific situation may affect the households' behaviour.

The households were not already BEV owners, which for sure are a positive selection of people. But also possible near-future buyers, the early adopters/early majority, are a positive selection. Our group of households, which has first accepted logging of their CVs for the sake of BEV research, and then accepted a BEV trial period belong probably to these segments

The analysis here is based on some assumptions and simplifications. The BEV range was assumed to always be 120 km. The perceived real range can be quite varying in the different households under various conditions such as, for instance, the considerable variation in outdoor temperature in south-west Sweden and the use of studded winter tyres for parts of the year. This may have led to an overestimate of the potential BEV driving and therefore an underestimation of the actual utilization of this potential.

Only home charging was assumed. In reality many households have used outside home charging. Somehow including outside-home charging in the potential would increase it and the option utilization would be comparably lower. The power rate of charging was not included as a limiting factor in the estimate of the potential driving. However, previous analyses have shown that this may decrease the potential, but to a minor extent [1].

The most pronounced result is maybe the difference in options utilization between single and overlap trips. Why this difference? Actually, most households claimed that the EV was their "first choice".[2] As concluded earlier, all but one household used the BEV more than the CV in single trips below BEV range. For single trips the "first choice" is apparent. But maybe not so for overlap trip; an extensive utilization of the options requires the BEV is used preferably for the longest trips. But both cars are often in overlap trips used (occupied) for around 10 hours. Maybe this gives less of a feeling of not using the BEV; it is less obvious that the driving (in kms) should be maximized, rather than just the occupation (in hours). The choice for overlap trips is also more complicated, involving more persons, driving and errands and maybe more habitual driving (daily commuting), etc.

After an initial market period of mostly short-range BEVs there is now an ongoing race towards larger batteries. But as we have shown, it can be enough with a smaller battery in multi-vehicle households, if the cars are wisely utilized for the inclusion of the BEV. For increased rate in BEV uptake it may be important that car manufacturers and dealers offer different battery sizes, and maybe also that the cars are prepared for a flexible capacity upgrading to accommodate for changing requirements and second-hand market. In the long run, the market will mature and the car buyers will be more aware of different BEV properties and how they fit their households' car movement patterns. In the meantime, more public education on BEV ranges and how they may fit into multi-car households can facilitate BEV market uptake by increasing the acceptance of well-suited short-range and cheaper BEVs in these households.

Because of the current market tendency with lower specific costs for batteries exchanged for larger batteries, the market expansion problem due to high BEV upfront cost has prevailed. Although more people or households can find a BEV economically viable, they still have to finance the initial purchase.[3] The combined age of the two cars in our 25 households varied between 9 and 23 years, with an average of 15.5 years. Thus not new cars. For these households, if buying a BEV today, it is almost inevitably a new car, and therefore involve a high initial cost compared to the value of the prevailing cars. Households wanting to keep the

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[2] In this study we have deliberately avoided use of the interviews but this is apparently a (minor) exception.

[3] Private leasing could be an alternative. But also the private leasing costs can be high, the leasing firms taking height for the uncertainty in second car values for the BEVs. For instance, in Sweden many firms offer for ordinary fossil fuel cars private leasing contracts for monthly fees of 1% of the purchase price (e.g., a conventional car sold for 250 000 SEK can be leased for 2 500 SEK/month). BEVs offered as leasing cars have often monthly fees of not less than about 1.5%, although the leasing firm will benefit from a BEV bonus of around 6000€. This means that private leasing of BEVs will end up with around double the fee or more compared to a comparable CV.

capital cost for their cars down, therefore may need to combine a new BEV with a (much) older, cheaper, but otherwise versatile car. We saw for the households here, that they mostly chose to keep the most expensive car; it was in many cases the largest one and often also the newest. Buying a new BEV while keeping overall car capital costs down may need to involve not only the BEV purchase, but a consideration of the household vehicle fleet composition. This will increase the challenge of buying a BEV.

Acknowledgements

We gratefully acknowledge the support from the Electric Vehicles Demonstration Program at the Swedish Energy Agency (project numbers 35880-1 and 35880-2) and the support from the Swedish Electromobility Centre.

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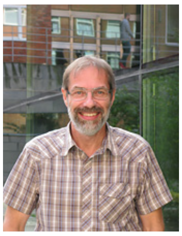

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